CLAIMS

1. An interface apparatus for interfacing motion of a user manipulable object with a computer system, said interface apparatus comprising:

a user manipulable object being physically contacted by a user;

a 3-D spatial mechanism coupled to said user object and including a plurality of members including a ground member, said spatial mechanism providing at least three degrees of freedom to said user manipulable object, said three degrees of freedom including two degrees of freedom provided in a planar workspace and a third degree of freedom provided as rotation of said planar workspace about an axis with respect to said ground member;

three actuators rigidly coupled to said ground member of said spatial mechanism, said actuators operative to apply forces in said three degrees of freedom to said user manipulable object in response to electrical signals from said computer system; and

a sensor for detecting a position of said user manipulable object in three-dimensional space and outputting sensor signals to said computer system.

2. An interface apparatus as recited in claim 1 wherein a first and second of said actuators apply force in said planar workspace and a third of said actuators applies force about said axis.

3. An interface apparatus as recited in claim 2 wherein at least some of said plurality of members of said spatial mechanism are formed as a closed loop linkage that provides said planar workspace.

4. An interface apparatus as recited in claim 3 wherein said closed loop linkage includes five members, and wherein each of said five members of said closed loop linkage is rotatably coupled to at least two other members of said linkage, said five member linkage providing two of said three degrees of freedom.

5. An interface apparatus as recited in claim 4 wherein said closed loop five member linkage includes:

a local ground member rotatably coupled to said ground member;

first and second base members, each base member being coupled to said local ground member; and

first and second central members, said first central member having an end coupled to said first base member and an end coupled to said user object, and said second central member having an end coupled to said second base member and an end coupled to said first central member.

6. An interface apparatus as recited in claim 4 wherein one of said members of said closed loop linkage is a rotatable carriage rotatably coupled to said ground member, said carriage providing said third degree of freedom.

7. An interface apparatus as recited in claim 2 further comprising transmitting a force from one of said actuators to said spatial mechanism using a capstan drive mechanism, said capstan drive mechanism including a cable and pully for transmitting said force.

~~8.~~ 5 An interface apparatus as recited in claim ~~6~~ further comprising two capstan drive mechanisms, each coupled between one of said actuators and said closed loop linkage, wherein each of said capstan drive mechanisms includes a drum coupled to said carriage and a pulley coupled to one of said actuators, wherein a member of said linkage is coupled to said drum, and wherein said drum is coupled to said pully by a cable such that said actuator is operative to rotate said pulley and thereby transmit force to said linkage with no substantial backlash.

9. An interface apparatus as recited in claim 2 wherein said user manipulable object includes a stylus.

10. An interface apparatus as recited in claim 2 wherein said user manipulable object includes at least a portion of a medical instrument.

11. An interface apparatus as recited in claim 4 further comprising a floating gimbal mechanism coupling said one of said plurality of members to said user manipulatable object to provide rotational movement for said object in a fourth degree of freedom.

~~12.~~ 11 An interface apparatus as recited in claim ~~11~~ 10 wherein said floating gimbal mechanism provides rotational movement for said user manipulable object in a fifth degree of freedom.

~~13.~~ 12 An interface apparatus as recited in claim ~~12~~ 11 further comprising:

a fourth degree of freedom transducer coupled between members of said floating gimbal mechanism; and

a fifth degree of freedom transducer coupled between members of said floating gimbal mechanism.

14. An interface apparatus as recited in claim 13 further comprising a capstan mechanism coupled between said members of said floating gimbal apparatus, said capstan mechanism including a pulley coupled to one of said fourth and fifth degree of freedom transducers and a rotatable drum coupled between said members of said floating gimbal mechanism.

~~15.~~ 13 An interface apparatus as recited in claim ~~12~~ 11 wherein said user manipulable object is rotatable about a longitudinal sixth axis of said object to provide a sixth degree of freedom for said object, and further comprising a sixth degree of freedom transducer coupled between said object and said floating gimbal mechanism.

16. An interface apparatus for interfacing motion of a user manipulable object with a computer system, said interface apparatus comprising:

a user manipulable object being physically contacted by a user;

a linkage of a plurality of members coupled to said user manipulable object, wherein said object has first and second degrees of freedom provided by said linkage;

a rotatable carriage coupled between said linkage and a ground, said rotatable carriage providing a third degree of freedom to said user manipulable object;

first, second, and third actuators coupled to said ground and operative to provide forces in said three degrees of freedom in response to actuator signals from said computer system; and

a plurality of sensors, at least one of said sensors coupled to said linkage and at least one of said sensors coupled to said rotatable carriage, said sensors sensing a position of said object in said three degrees of freedom and outputting sensor signals to said computer system.

17. An interface apparatus as recited in claim 16 wherein said linkage and said carriage form a closed loop five member linkage.

18. An interface apparatus as recited in claim 16 wherein transmission of force from said first and second actuators to said object along first and second degrees of freedom is provided via a capstan drive included for each of said first and second actuators, wherein said capstan drives are coupled between said first and second actuators, respectively, and said linkage.

28. A mechanism as recited in claim 27 further comprising a plurality of sensors coupled to said mechanism, said sensors sensing a position of said user manipulatable object in said first and second degrees of freedom.

29. A mechanism as recited in claim 27 wherein said second axis is substantially perpendicular to said first axis.

30. A mechanism as recited in claim 27 further comprising a linkage of members coupled between said user manipulatable object and said drum.

31. A mechanism as recited in claim 30 further comprising a second capstan drive, said second capstan drive including:

a second capstan drum coupled between said user manipulable object and said carriage and rotatable about a third axis to allow said user manipulable object to be moved in a planar workspace having said first degree of freedom and a third degree of freedom;

a second actuator coupled to said ground surface and being controllable to provide a force in said third degree of freedom of said user manipulable object; and

a second pulley coupled to said second actuator, said second pulley being coupled to said second capstan drum by a second flexible member.

32. A mechanism as recited in claim 31 further comprising a third actuator coupled to said ground surface, said third actuator providing a force in said second degree of freedom, wherein said three actuators are each coupled to said ground surface.

33. A mechanism as recited in claim 32 further comprising a third capstan drive coupled between said carriage and said third actuator, said third capstan drive including a third capstan drum rigidly coupled to said carriage and rotatably coupled to said ground surface, a third pulley coupled to said third actuator, and a third flexixible member coupled between said third drum and said third pulley.

34. A mechanism as recited in claim 33 wherein said flexible members are metal cables.

35. A mechanism as recited in claim 27 wherein said user manipulable object is a stylus.

36. A mechanism as recited in claim 27 wherein said user manipulable object is a medical instrument.

19. An interface apparatus as recited in claim 18 wherein transmission of force from said third actuator to said object is provided via a third capstan drive coupled between said carriage and said ground.

20. An interface apparatus as recited in claim 18 wherein said first and second capstan drives each include a capstan drum coupled to said carriage, a pulley coupled to a grounded actuator, and a flexible cable coupled between said capstan drum and said pulley, wherein torsional flexibility of said cable allows said carriage and drum to move with respect to said pulley.

21. An interface apparatus as recited in claim 16 further comprising a plurality of sensors operative to sense a position or an orientation of said object in fourth, fifth and sixth degrees of freedom of said object.

22. A mechanical interface apparatus for interfacing motion of a user manipulable object with a computer system, said interface apparatus comprising:

a user manipulable object being physically contacted by a user;

a 3-D spatial mechanism coupled to said user object and including a plurality of members including a ground member rigidly coupled to a ground, said spatial mechanism providing at least three degrees of freedom to said user manipulable object;

three actuators rigidly coupled to said ground member of said spatial mechanism, said actuators operative to apply forces in said three degrees of freedom to said user manipulable object in response to electrical signals from said computer system, said three actuators being decoupled in force from each other such that none of said actuators can apply a force to any of said other actuators; and

a sensor for detecting a position of said user manipulable object in three-dimensional space and outputting sensor signals to said computer system.

23. A mechanical interface apparatus as recited in claim 22 wherein said actuators provide forces in said three degrees of freedom using tensioned cables, wherein tension in each of said cables is independent of a tension in said other cables.

24. A mechanical interface apparatus as recited in claim 23 further comprising two capstan drive mechanisms, each coupled between one of said first and second actuators and said plurality

of members, wherein each of said capstan drive mechanisms includes a drum coupled to one of said members and a pulley coupled to one of said actuators, wherein a member of said linkage is coupled to said drum, and wherein said drum is coupled to said pully by said cable such that said actuator is operative to rotate said pulley and thereby transmit force to said linkage with no substantial backlash.

25. A mechanical interface apparatus as recited in claim 22 wherein said three degrees of freedom including two degrees of freedom provided in a planar workspace and a third degree of freedom provided as rotation of said planar workspace about an axis with respect to said ground member.

26. A mechanical interface apparatus as recited in claim 25 wherein said two of said degrees of freedom are in a planar workspace provided by a parallel link mechanism, and a third of said degrees of freedom is provided by rotating said parallel link mechanism about an axis with respect to said ground member.

27. A mechanism for providing computer-controlled forces on a user manipulable object, the mechanism comprising:

a user manipulable object graspable by a user;

an actuator coupled between a ground surface and said user manipulable object and being controllable to provide a force in a degree of freedom of said user manipulatable object;

a capstan drive coupled between said user manipulable object and said actuator, said capstan drive including a capstan drum coupled to said user manipulable object and rotatable about a first axis and a rotatable pulley coupled to and rotatable by said actuator, wherein a flexible member is coupled between said drum and said pulley to transmit rotational force between said drum and said pulley; and

a carriage rotatable with respect to said ground surface about a second axis, wherein said drum is rotatably coupled to said carriage, and wherein said capstan drum and said user manipulable object may be rotated about said second axis while said actuator and said pulley are fixed to said ground surface and do not rotate about said second axis, wherein said flexible member is twisted from said rotation about said second axis;

whereby said user manipulable object is provided with a first degree of freedom about said first axis and a second degree of freedom about said second axis.

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37. A mechanism as recited in claim 30 wherein said user manipulable object is coupled to said linkage of members by a floating gimbal mechanism that provides at lesat two additional degrees of freedom to said user manipulable object.

38. A hman-computer interface mechanism comprising:

a user manipulable object;

a linkage of members providing two degrees of freedom to said user manipulable object;

a floating gimbal mechanism coupling said user manipulable object to said linkage of members, said floating gimbal mechanism including:

a plurality of rotatably coupled gimbal members, said gimbal members providing two rotary degrees of freedom said user manipulable object;

a sensor provided for each of said gimbal members for measuring a position of said members relative to each other in one of said rotary degrees of freedom, such that each sensor measures motion in a different rotary degree of freedom; and

a capstan mechanism coupled between each of said sensors and one of said gimbal members, each of said capstan mechanisms including a capstan drum rotatable about an axis of one of said rotary degrees of freedom and a pulley coupled to said sensor and coupled to said drum by a flexible member.

39. An interface mechanism as recited in claim 38 wherein said floating gimbal mechanism is rotatably coupled to said linkage of members, thereby providing an additional rotary degree of freedom to said user manipulable object.

40. An interface mechanism as recited in claim 38 wherein an intermediate member is coupled between said gimbal members of said floating gimbal mechanism.

41. An interface mechanism as recited in claim 38 wherein said two rotary degrees of freedom provided by said floating gimbal mechanism are substantially perpendicular to each other, such that axes of rotation for said rotary degrees of freedom are substantially mutually perpendicular.

42. An interface mechanism as recited in claim 41 wherein said flexible member is a cable.

43. An interface mechanism as recited in claim 40 wherein said gimbal members are substantially U-shaped and are coupled to each said intermediate member approximately at legs of said U-shape.

44. An interface mechanism as recited in claim 38 wherein said capstan mechanism provides at least a 4:1 mechanical reduction in motion between said capstan drum and said pulley.

45. An interface mechanism as recited in claim C5 wherein said user manipulable object is a stylus.

46. An interface mechanism as recited in claim C5 wherein said user manipulable object is at least a portion of a medical instrument.

47. A method for interfacing motion of a user manipulable object with a computer system, the method comprising:

providing a linkage of members movable such that an object engaged with said linkage has first and second degrees of freedom;

providing a rotatable carriage between said linkage and a ground, said rotatable carriage providing a third degree of freedom to said object;

actuating a force in each of said three degrees of freedom using first, second, and third actuators, wherein said three actuators are each fixed to a single ground; and

sensing a position of said object in each of said three degrees of freedom; and

providing electrical signals to and from a computer system for controlling said force and relaying said position.

48. A method as recited in claim 47 wherein said linkage is a closed loop five member linkage.

49. A method as recited in claim 47 wherein a transmission of force from said first and second actuators to said object along first and second degrees of freedom is provided via a capstan drive included for each of said first and second actuators, wherein said capstan drives are coupled between said first and second actuators, respectively, and said linkage.

50. A method as recited in claim 49 wherein transmission of force from said third actuator to said object is provided via a third capstan drive coupled between said carriage and said ground.

51. A method as recited in claim 49 wherein said first and second capstan drives each include a capstan drum coupled to said carriage, a pulley coupled to a grounded actuator, and a flexible cable coupled between said capstan drum and said pulley, wherein torsional flexibility of said cable allows said carriage and drum to move with respect to said pulley.

52. A method as recited in claim 47 further comprising a step of transducing an electrical signal for fourth, fifth and sixth degrees of freedom of said object using fourth, fifth, and sixth transducers, respectively.

53. A surgical simulator for simulating medical surgery on a patient, the simulator comprising:

a human body part model having a point of entry;

a medical instrument provided on a first side of said human body part model, said medical instrument extending through said point of entry of said model to a second side of said model;

a floating gimbal device coupled to said medical instrument, said floating gimbal device providing three degrees of freedom to said medical instrument;

a force feedback interface device coupled to said floating gimbal device, said force feedback interface device providing movement to said medical instrument in three dimensions separate from said three degrees of freedom and providing forces to said medical instrument in said three dimensions, said force feedback device being coupled to a ground on said second side of said human body part model and including three actuators for generating said forces; and

a plurality of sensors coupled to said gimbal mechanism and to said force feedback interface device for sensing a position and orientation of said medical instrument.

54. A surgical simulator as recited in claim 53 wherein said three actuators are fixed to said ground and stationary with respect to said ground.

55. A surgical simulator as recited in claim 54, wherein said sensors and said three actuators are coupled to a host computer.

56. A surgical simulator as recited in claim 55, wherein said sensors and said three actuators are coupled to a local microprocessor that is coupled to said host computer, said local microprocessor being separate from said host computer.

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